Anisotropy of bottom loss in marine sediments

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***Abstract*-We observed anisotropy in the acoustic reflection amplitudes from the seafloor at Hydrate Ridge on the Oregon Margin. We analyzed acoustic data from several OBS receivers and several sound-source lines with one line being perpendicular to the others. We used time windows to isolate the acoustic data that contained the most information regarding the seafloor reflectivity. The bottom loss is directly related to these observed reflection strengths with some restrictions. The observed higher reflection strengths for the east-west line (perpendicular to bathymetric contours) than to reflection strengths on the north-south lines is unexpected and so far unexplained. We expect that the primary causes of variations in the reflectivity are due to scattering and from heterogeneity.**

I. INTRODUCTION

The vast majority of current and past research into sediment anisotropy has been focused on wave-speed anisotropy in consolidated sediment. Studies on unconsolidated deep marine sediments are rare, and none are known that specifically address attenuation anisotropy. Anisotropy of wave-speed, attenuation, and scattering can cause changes in seafloor reflection coefficients that result in errors in prediction of bottom loss, particularly near critical angles, at small grazing angles, and at low frequencies (< 1 kHz). We analyzed two entirely different data sets, each of which exhibit anisotropy in reflection amplitude.

II. THE DATA

We analyzed data acquired by N. Bangs and I. Pecher of the Jackson School of Geosciences, University of Texas at Austin during a shear wave study of Hydrate Ridge, Oregon Margin during August and September of 2002. The data used for this paper were acquired by several ocean bottom seismometers (OBS) with a two GI gun source configured in harmonic mode with both the generator and injector set at 105 cu. in. Each OBS contains a hydrophone and three orthogonal geophones. Due to the low sampling rate of these instruments, the hydrophones and geophones used anti-aliasing filter of 80 Hz and 50 Hz respectively. Many OBS tracks were acquired but only four OBS tracks were analyzed; OBS 24 acquired in an east-west line across hydrate ridge, and OBS 18, 19, and 20 acquired along north-south lines on the eastern flank of the ridge (Fig. 1). Thus OBS line 24 is perpendicular to tracks OBS 18, 19, and 20 and these data offer a good opportunity to examine some anisotropic aspects of the geoacoustics of these sediments. These data as well as vertical seismic profile (VSP) data were previously analyzed for sound speed anisotropy and although there was significant sound speed anisotropy at the top of Hydrate Ridge, there was no sound speed anisotropy measured on the flank of Hydrate Ridge where these OBSs were located [1].

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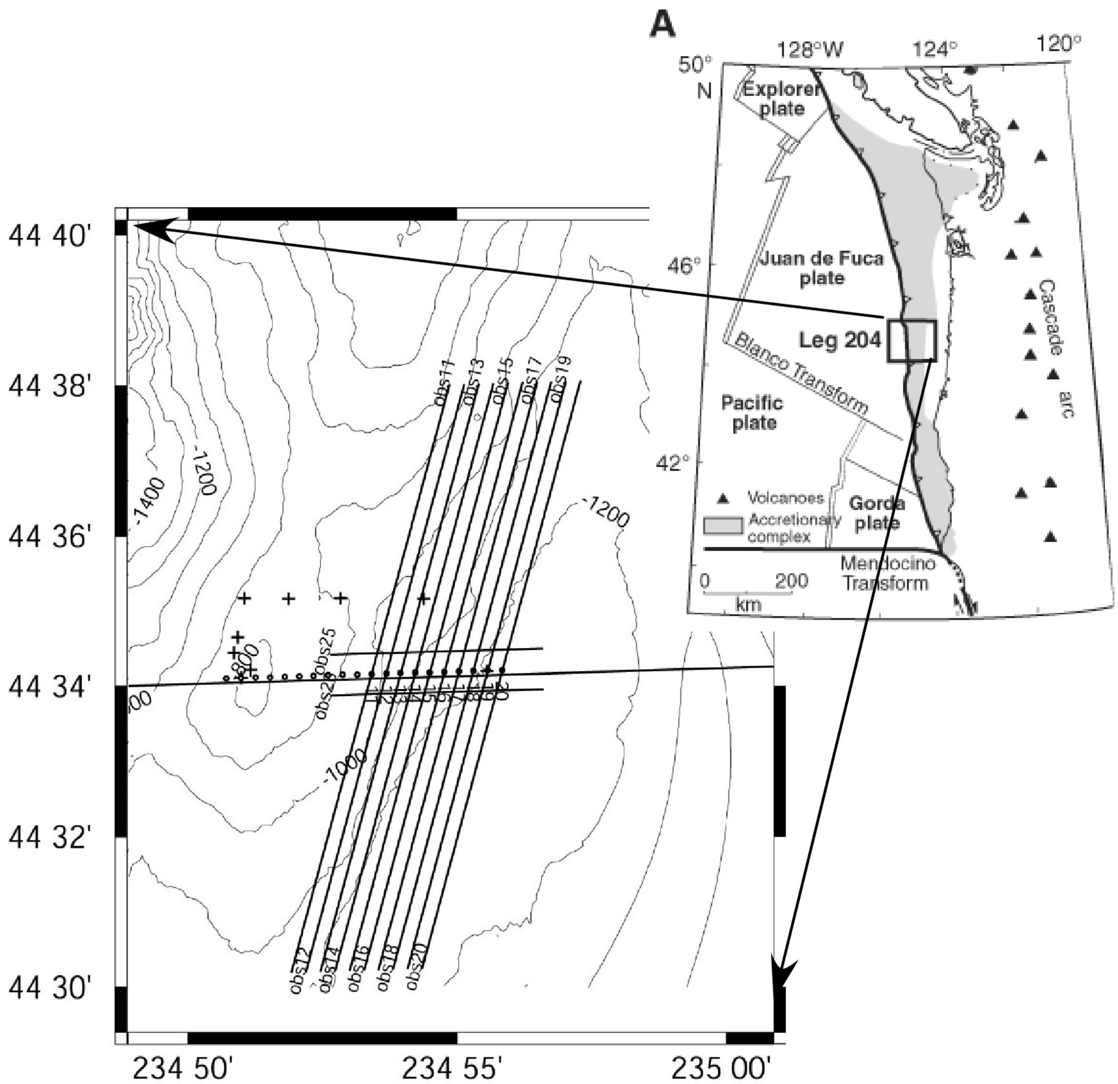

Fig. 1. Location map for the OBS sites and the GI gun source lines. This paper examines data from OBS sites 18, 19, and 20 as well as the line "obs24" which was received by OBS 19.

III. Processing

Since our objective is to test the seafloor geoacoustic response as a function of direction, we isolated the data that interacts the most with the sub seafloor. The first arrivals at the OBS sensors are dominated by the direct wave and seafloor reflections from the immediate vicinity of the OBSs; between 0.8 s and 2 s in Fig. 2. The second arrival group consists of seafloor and sub seafloor reflections that are then reflected off the sea surface and then go back down to the OBS sensors; between 2.5 and 4 s in Fig. 2. We isolated the second arrival group with time windows that we picked for each OBS using the first peak of the second arrival. The arrival angles were calculated from the local water depth determined by the travel time of the peak of the direct wave. We used both 0.5 s windows and 1.5 s windows. The 0.5 s windows are less influenced by the noise in OBSs 20 and 24 but do not include the deeper reflectors that have stronger interactions with the acoustic waves. Both our signal and the noise are broadband so a frequency based noise filter would not eliminate signal as well as noise.

Our data displays show the relative amplitudes of measured reflections from the seafloor near the OBS locations. The bottom loss is the ratio of these measured amplitudes with a perfectly reflecting smooth surface. Without absolute reflection references we can only make relative comparisons between our measured reflections and our data displays compare the measured amplitudes over a range of angles for different line directions.

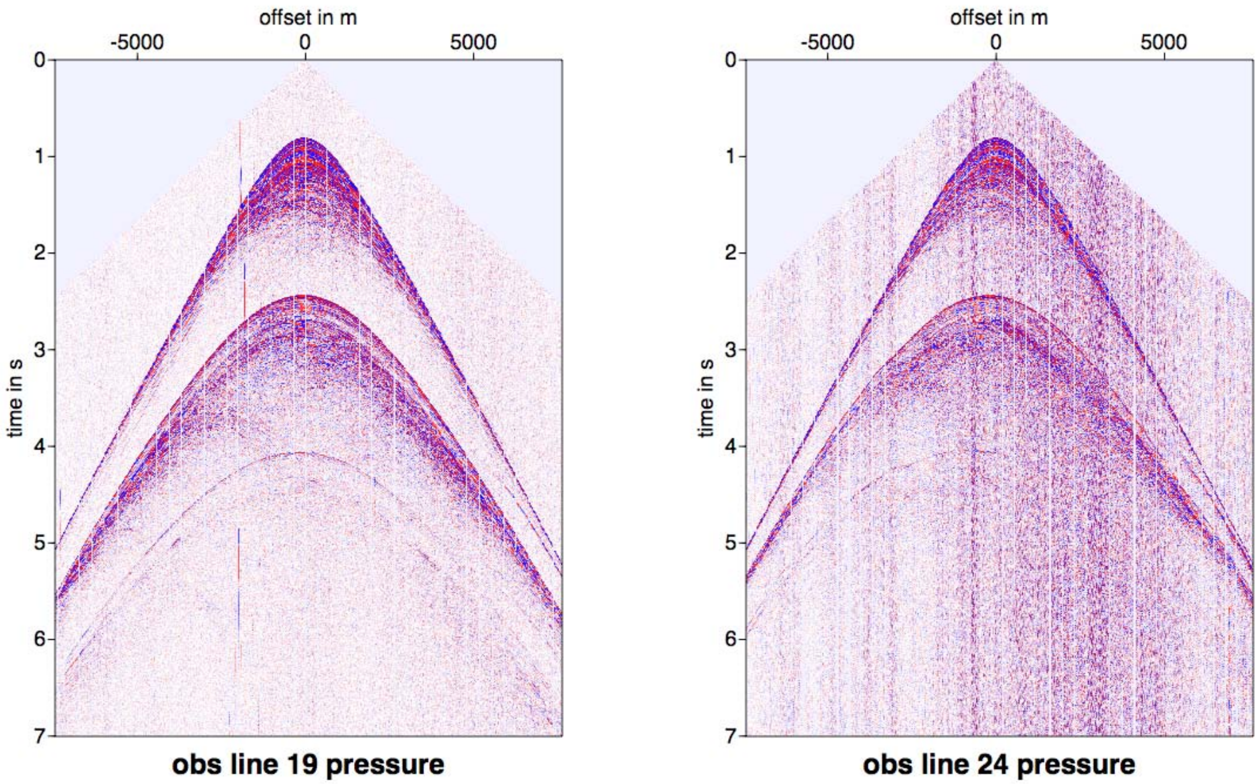

Fig. 2. Raw data from two separate source lines called obs19 and obs24 shot to the same pressure sensor on OBS 19. The first prominent hyperbolas are from the direct arrival followed immediately by reflections and scattering from geological features near the OBS. The second prominent hyperbolas with a minimum time of about 2.5 s are from the first multiple that consists of a seafloor reflection and a sea surface reflection. The seafloor reflection in this first multiple includes reflections from subsurface features and is the subject of most of the analysis of this paper. The much weaker second multiple is the hyperbolas with a minimum time of about 4 s. OBS line 24 has a higher level of noise which obscures some of the finer structures.

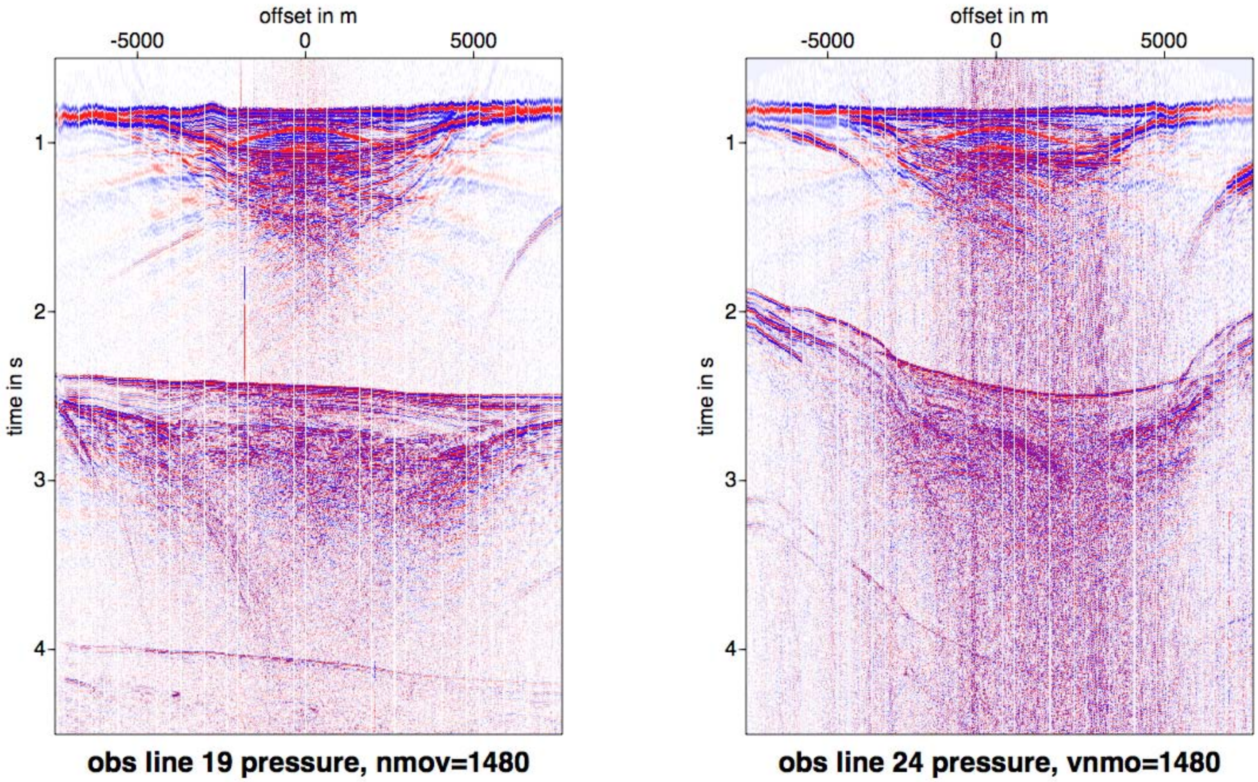

Fig. 3. Moveout corrected plots of the data shown in Fig. 2. This display flattens the hyperbolas and is a better way for showing some of the geological features. These two lines were shot to the same OBS that was placed on the flank of a shallow basin (Fig. 1). The shape of this basin is apparent in the first multiple for line 24 which crosses the basin. Line 19 was along the strike of the flank and the first multiple shows only a slight down-slope from south to north (left to right). There is a significant subsurface reflector appearing about 0.25 s after the seafloor and shows strong refractions in the first arrival group and more clearly as the top of a more reflective structure in the second arrival. All data exhibit significant reflectivity from layered sediments.

IV. Calibration

Our data came from two different types of OBSs with different sensitivities for their hydrophones and geophones. We used the response of the direct waves on these sensors as a calibration measurement. The OBS 18 and 20 hydrophones are 3.4 times as sensitive as the OBS 19 hydrophones (Fig. 4). OBS line 24 was actually received by OBS 19 and these two lines are a check on the consistency of the sensors and the source levels (Fig. 4). A similar plot of the vertical geophone signals for these same OBSs showed that the OBS 18 and 20 geophones are 2.0 times as sensitive as the OBS 19 geophones (not shown).

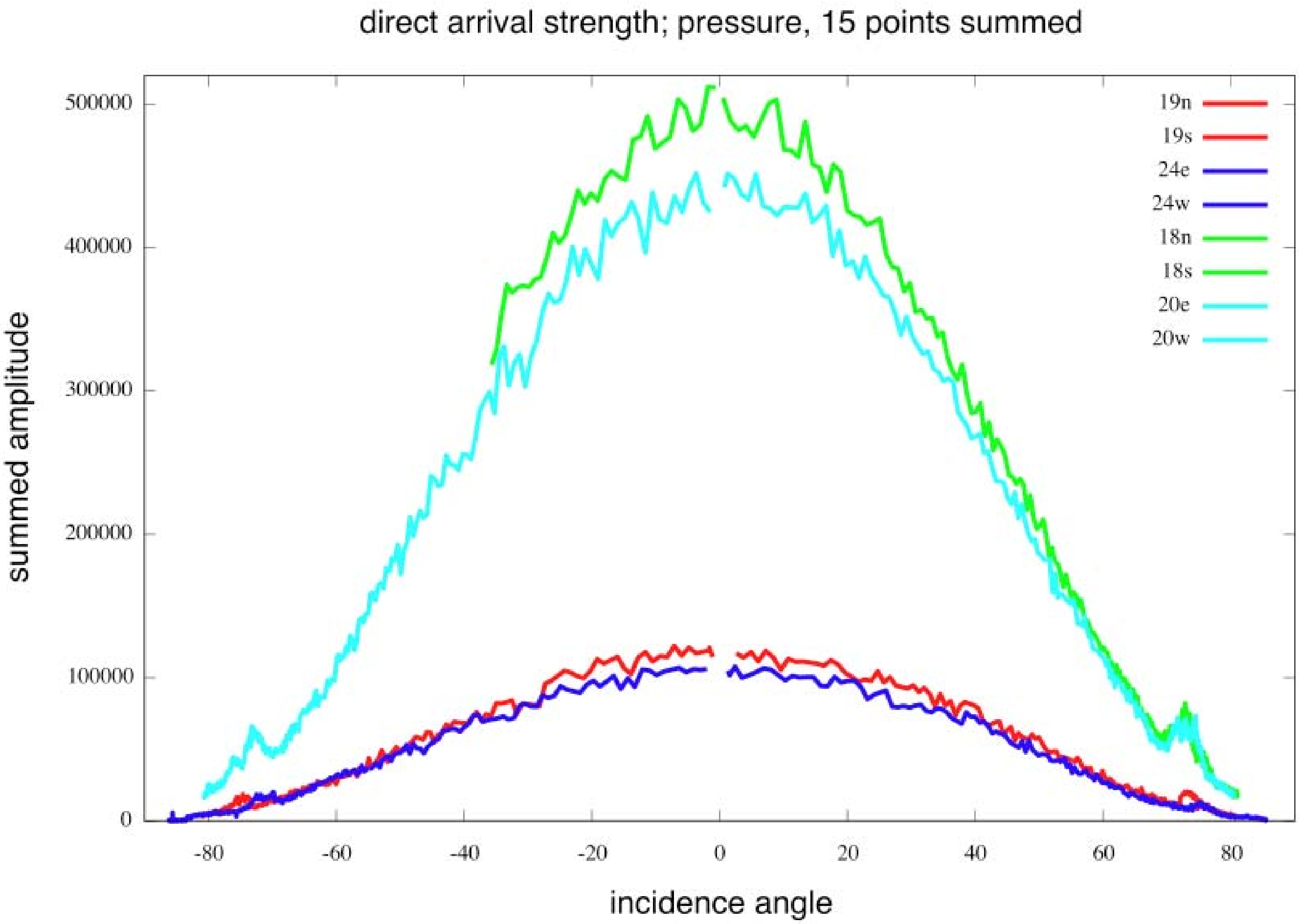

Fig. 4. These are the peak amplitudes of the direct wave received by the hydrophones. These are also the first arrivals visible in Fig. 2 as the top hyperbolas. The OBS 18 and 20 hydrophones have 3.4 times the sensitivity as the OBS 19 hydrophone. The north and east lines are plotted with positive incidence angles.

V. RESULTS

The summed signal traces of the first multiples (Fig. 2) isolated with time windows show the acoustic reflections and scattering from the seafloor and sub seafloor features. The summed signals for the three OBSs shown in Fig. 5 agree well at vertical incidence (0°). The reflection amplitudes decrease for small incidence angles for the two north-south lines (OBS 18 and 19) while they increase considerable for the east-west line (OBS 24) (Figs. 5 and 6). The reflection strengths for lines 18 and 19 agree well with each other over most of their ranges in angles and include peaks at incidence angles near 50°. The reflection strengths calculated over the 0.5 s time windows have smaller overall values, due to the smaller amount of data included in the summations, and show considerably more noise (Fig. 6) than the reflection strengths using the 1.5 s time windows (Fig. 5) However, the general character of the curves remain the same. The signal to noise ratio is higher in the shorter time windows, but the line with the most noise, OBS 24, has nearly the same relative amplitudes in either the 0.5 s or the 1.5 s windows (Figs. 2 and 3). The longer time windows include data from acoustic energy that penetrates deeper into the sediment, and is only slightly higher amplitude than the noise.

Reflection amplitudes for lines OBS 18 and 19 are symmetrical relative to a vertical (0°) incidence angle while OBS line 24 is asymmetric. Line OBS 24 appears to have symmetric peaks at about 40° that could be interpreted as a critical angle while lines OBS 18 and 19 have such peaks at 50°.

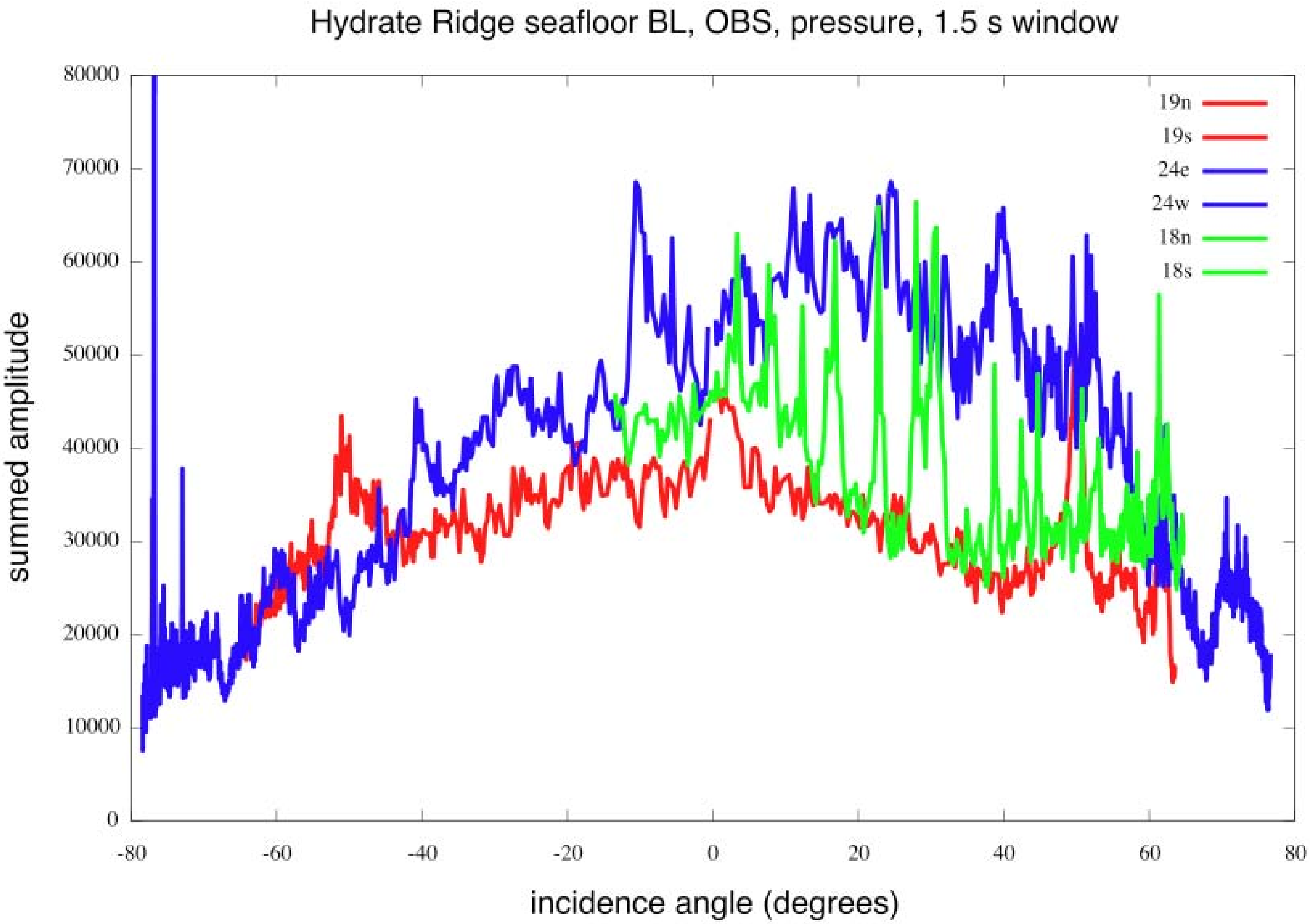

Fig. 5. The bottom loss is plotted in terms of the summed amplitudes of the time series from the hydrophones. These are the amplitudes of the first multiple using a 1.5 s window. The amplitude of each trace was summed over a time window starting just before the peak of the first multiple. Lines 18 and 19 are north-south lines with north being on the right side of the plot and line 24 is the east-west line with east on the right side of the plot. OBS 18 had numerous noise events in many of the traces that show up as spikes in these data.

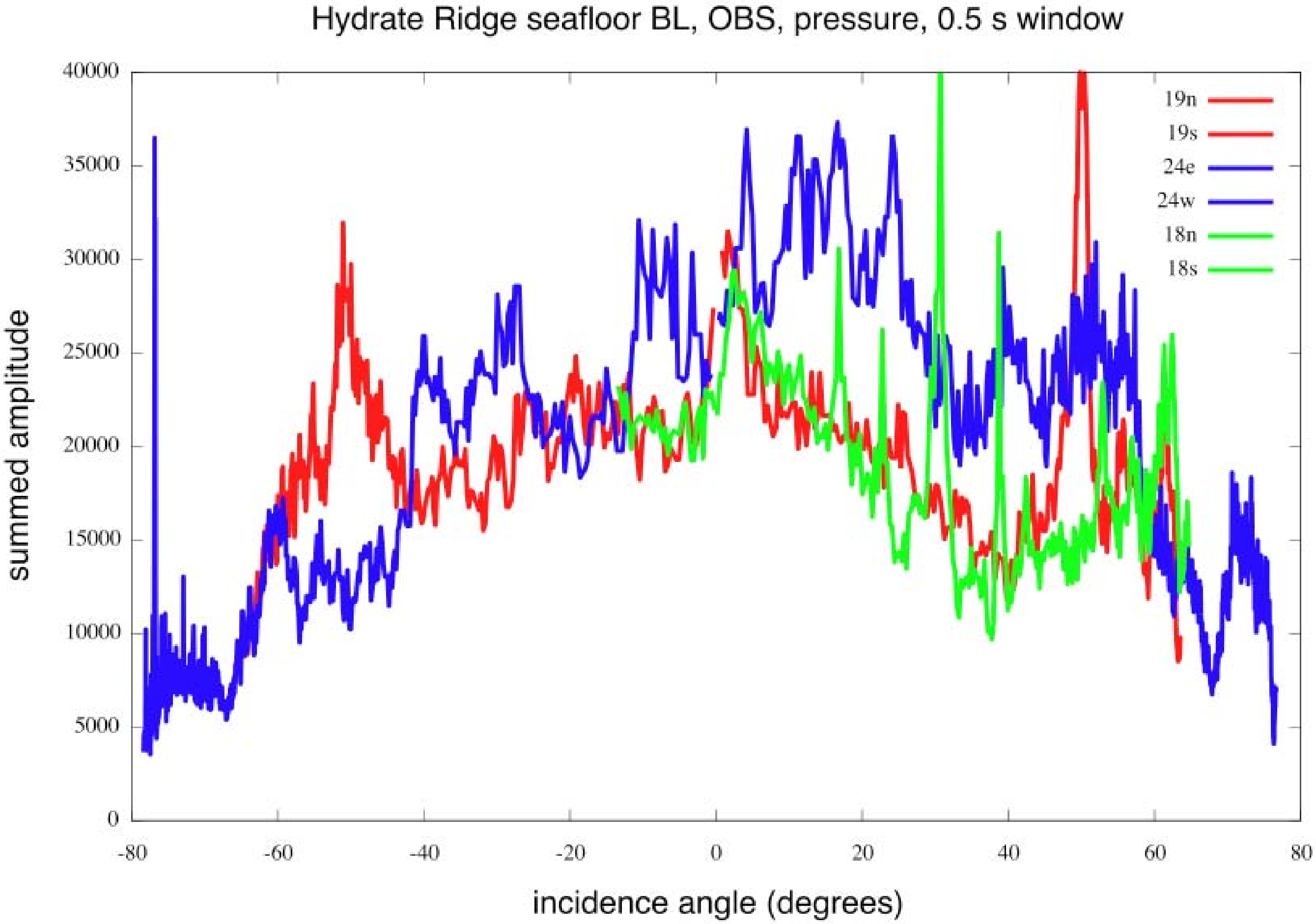

Fig. 6 These are the same data as shown in Fig. 5 with the exception that a 0.5 s window was used. These data contain less energy from sub seafloor reflectors and the number of spikes from noise in the OBS 18 data is reduced.

VI. Discussion

These observed reflection values are directly related to what is often called bottom loss but with caveats regarding absolute values, multiple reflections and scatterings, and incidence angles for reflections from features below the seafloor. The seafloor reflections that we measured here come from several causes and are not simply due to the physical properties such as sound speed and density of the sediments. The seafloor is fairly smooth in this area and rough surface scattering at these frequencies (<50 Hz) is probably a minor contributor to the overall seafloor reflections. Likewise, intrinsic (absorptive) attenuation is not likely to be a major contributor to the decrease in reflection strengths. Lateral heterogeneity may be a strong factor here since multiple discontinuous features are observed in seismic profiles here and there are variations of as much as 20% in the sediment sound speeds here [1]. The seafloor bounce-point changes for these data as the source moves away from the OBS. The maximum ranges for lines OBS 18n, 19n, and 19s exceed 7 km and the seafloor bounce point is 2/3 that distance. Thus the reflecting seafloor patch for the combined north and south portions of line OBS 19 moves more that 10 km and the rapid fluctuations in reflection amplitudes may be largely due to either changes in the seafloor properties or due to the many small reflectors visible in the seismic profiles [1] and in the moveout corrected OBS data (Fig. 3).

The higher reflection amplitudes for both the east and west segments of line OBS 24 demonstrate that there is anisotropy in the seafloor reflection amplitudes at this location. The cause of this anisotropy is so far unexplained. OBS line 24 crosses the axis of Hydrate ridge and the acoustic energy that dives below the seafloor must pass through any of the north-south trending faults that were observed on Hydrate Ridge [1]. We expect that faults perpendicular to the ray paths of the acoustic energy would absorb, scatter, and otherwise reduce the amplitude of the acoustic energy passing through and yet we observe the opposite. The asymmetry of the reflection strength of line OBS 24 is also unexplained. The reflection amplitudes for the two lines OBS 18 and 19, which are spaced about 500 m apart, agree well with each other and yet the same reflectivity measurements from an east-west line exceeds those values even at small incidence angles which correspond to bounce points very close to the OBS locations.

Some of these causes of anisotropy can be tested with modeling. There are well-accepted methods for modeling anisotropic sound speeds, attenuations, and scattering. Modeling the variations caused by geological structures is also possible but would require some detailed mapping of the structures from seismic profiles, which we have only for line OBS 24.

VII. Conclusions

We observed anisotropy in the acoustic reflection amplitudes of the seafloor near Hydrate Ridge on the Oregon Margin. These anisotropic reflections can be related to bottom loss with certain restrictions. The inherent physical properties of the sediment here may or may not be anisotropic but other explanations such as scattering and heterogeneity may be more important at this site. The larger reflection strengths for line OBS 24, the east-west line, than for the north-south lines is unexpected and as of now, unexplained.

Acknowledgment

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References

[1] D. Kumar, M. K. Sen, N. L. Bangs, C. Wang, and I. Pecher, “Seismic anisotropy at Hydrate Ridge,” *Geophysical Research Letters,* vol. 33, pp. L01306, 2006.